

What is claimed is:

1. An electrochemical system, comprising:
 - a reversible fuel cell system which generates electrical energy and reactant product from fuel and oxidizer in a fuel cell mode and which generates the fuel and oxidant from the reactant product and the electrical energy in an electrolysis mode;
 - a reactant product delivery device which is adapted to supply the reactant product to the reversible fuel cell system operating in the electrolysis mode, in addition to or instead of the reactant product generated by the reversible fuel cell system in the fuel cell mode; and
 - a fuel removal device which is adapted to remove the fuel generated by the reversible fuel cell system operating in the electrolysis mode from the electrochemical system.
2. The system of claim 1, further comprising a fuel storage device and a reactant product storage device.
3. The system of claim 2, wherein:
 - the reactant product delivery device comprises a reactant product conduit which is connected to the reactant product storage device to provide the reactant product to the reactant product storage device from outside of the electrochemical system; and
 - the fuel removal device comprises a fuel conduit which is connected to the fuel storage device to deliver fuel from the fuel storage device outside of the electrochemical system.
4. The system of claim 3, wherein:
 - reactant product conduit comprises a water conduit; and
 - the fuel conduit comprises a hydrogen conduit.
5. The system of claim 3, wherein:

reactant product conduit comprises a water conduit and a carbon dioxide conduit; and

the fuel conduit comprises a methane conduit.

6. The system of claim 3, further comprising a power management subsystem which is adapted to control an operation of the reversible fuel cell system and to provide electrical energy to and from the reversible fuel cell system.

7. The system of claim 3, wherein the reversible fuel cell system comprises a stack of plurality of reversible fuel cells, which generate the electrical energy in the fuel cell mode and which generate the fuel in the electrolysis mode.

8. The system of claim 7, wherein the reversible fuel cells comprise a stack of solid oxide regenerative fuel cells.

9. The system of claim 7, wherein the reversible fuel cells comprise PEM fuel cells.

10. The system of claim 1, wherein the reversible fuel cell system comprises a fuel cell which generates electrical energy and an electrolyzer cell which generates fuel.

11. The system of claim 1, further comprising a renewable energy source electrically connected to the reversible fuel cell system, such that an excess capacity of the renewable energy source is used to provide electrical energy to the reversible fuel cell system operating in the electrolysis mode to generate excess fuel to be provided to the fuel removal device.

12. An electrochemical system, comprising:

a reversible fuel cell system which generates electrical energy and reactant product from fuel and oxidizer in a fuel cell mode, and which generates the fuel and oxidant from the reactant product and the electrical energy in an electrolysis mode;

a second means for providing excess reactant product to the reversible fuel cell system operating in the electrolysis mode from outside the electrochemical system, in addition to or instead of the reactant product generated by the reversible fuel cell system in the fuel cell mode, such that fuel in excess of fuel required to operate the reversible fuel cell system in the fuel cell mode is generated in the electrolysis mode over a predetermined number of operating cycles; and

a third means for removing the excess fuel generated by the reversible fuel cell system operating in the electrolysis mode from the electrochemical system.

13. The system of claim 12, further comprising a renewable energy source electrically connected to the reversible fuel cell system, such that an excess capacity of the renewable energy source is used to provide electrical energy to the reversible fuel cell system operating in the electrolysis mode to generate the excess fuel to be provided to the third means.

14. The system of claim 12, wherein the reversible fuel cell system is electrically connected to a fourth means for generating electrical energy from sun light, for providing the electrical energy to the reversible fuel cell system during daytime periods to generate fuel, and for allowing the reversible fuel cell system to generate electrical energy during night time periods, wherein night time periods are shorter than day time periods.

15. The system of claim 12, wherein the reversible fuel cell system is electrically connected to a fifth means for generating renewable electrical energy and for using excess capacity to provide electrical energy to the reversible fuel cell system operating in the electrolysis mode to generate the excess fuel.

16. The system of claim 15, wherein the fifth means is a means for generating electrical energy from sun light and for using the excess capacity during a first half of its designed lifespan.

17. The system of claim 15, wherein the fifth means is a means for generating electrical energy from wind and for using the excess capacity during periods when wind speed exceeds a predetermined wind speed required to generate a desired amount of electrical energy.

18. The system of claim 15, wherein the fifth means is a means for generating electrical energy from tidal force and for using the excess capacity during periods when the tidal force exceeds a predetermined tidal force required to generate a desired amount of electrical energy.

19. The system of claim 12, wherein the third means is a means for providing the fuel removed from the reversible fuel cell system into an airborne vehicle, a water based vehicle, a land based vehicle, a chemical reaction in a chemical manufacturing process, or a heating system of a building containing the first means.

20. A method of operating an electrochemical system containing a reversible fuel cell system, comprising:

cyclically operating the reversible fuel cell system in a fuel cell mode to generate electrical energy and reactant product from fuel and oxidizer and in an electrolysis mode to generate the fuel and oxidant from the reactant product and the electrical energy;

providing excess reactant product to the reversible fuel cell system operating in the electrolysis mode from outside the reversible fuel cell system, in addition to or instead of the reactant product generated by the reversible fuel cell system in the fuel cell mode, such that fuel in excess of fuel required to operate the reversible fuel cell system in the fuel cell mode is generated in the electrolysis mode over a predetermined number of operating cycles; and

removing the excess fuel generated by the reversible fuel cell system operating in the electrolysis mode from the electrochemical system.

21. The method of claim 20, wherein the reversible fuel cell system generates more fuel in the electrolysis mode than it consumes in the fuel cell mode over the predetermined number of cycles.

22. The method of claim 21, wherein the reversible fuel cell system operates at a higher current level in the electrolysis mode than in the fuel cell mode over the predetermined number of cycles.

23. The method of claim 22, wherein:

the reversible fuel cell system is electrically connected to a photovoltaic energy generation system which provides electrical energy to the reversible fuel cell system during daytime to generate fuel;

the reversible fuel cell system generates electrical energy during night time;
and

the night time load on the reversible fuel cell system at least during a portion of the night time period is lower than a peak load that the reversible fuel cell system is capable of providing.

24. The method of claim 22, wherein the reversible fuel system is operated at a load lower than a peak load that the reversible fuel cell system is capable of providing at least during a portion of a time that the reversible fuel cell system operates in the fuel cell mode.

25. The method of claim 21, wherein the reversible fuel cell system operates for a longer duration in the electrolysis mode than in the fuel cell mode over the predetermined number of cycles.

26. The method of claim 25, wherein:

the reversible fuel cell system is electrically connected to a photovoltaic energy generation system which provides electrical energy to the reversible fuel cell system during daytime to generate fuel;

the reversible fuel cell system generates electrical energy during night time;
and
night time periods are shorter than day time periods.

27. The method of claim 21, wherein the reversible fuel cell is electrically connected to a renewable energy source, such that an excess capacity of the renewable energy source is used to provide electrical energy to the reversible fuel cell operating in the electrolysis mode to generate the excess fuel.

28. The method of claim 27, wherein the renewable energy source comprises a photovoltaic system which contains the excess capacity during a first half of its designed lifespan.

29. The method of claim 27, wherein the renewable energy source comprises a wind turbine system which is designed to provide a minimum required amount of electrical energy at a predetermined minimum wind speed and which contains the excess capacity during periods when the wind speed exceeds the predetermined minimum wind speed.

30. The method of claim 27, wherein the renewable energy source comprises a tidal energy generation system which is designed to provide a minimum required amount of electrical energy at a predetermined minimum tidal force and which contains the excess capacity during periods when the tidal force exceeds the predetermined minimum tidal force.

31. The method of claim 20, wherein the step of providing the excess reactant product comprises providing the excess reactant product to the reversible fuel cell system operating in the electrolysis mode from outside the electrochemical system in addition to a stored reactant product generated by the reversible fuel cell system in the fuel cell mode.

32. The method of claim 20, wherein the step of providing the excess reactant product comprises providing the excess reactant product to the reversible fuel cell system operating in the electrolysis mode from outside the electrochemical system instead of the reactant product generated by the reversible fuel cell system in the fuel cell mode.

33. The method of claim 20, further comprising storing the fuel and the reactant product produced by the reversible fuel cell system.

34. The method of claim 33, wherein:
at least a portion of the stored fuel is removed from the reversible fuel cell system through a fuel conduit; and
at least a portion of the reactant product is provided to the reversible fuel cell system from outside the electrochemical system through a reactant product conduit.

35. The method of claim 33, wherein at least a portion of the stored fuel is removed from the electrochemical system by removing a fuel storage vessel from the electrochemical system.

36. The method of claim 20, wherein:
the reactant product comprises water; and
the fuel comprises hydrogen.

37. The method of claim 20, wherein:
the reactant product comprises water and carbon dioxide; and
the fuel comprises methane.

38. The method of claim 20, wherein:
the reversible fuel cell system comprises a stack of a plurality of reversible fuel cells, which generate electrical energy in the fuel cell mode and which generate fuel in the electrolysis mode; and

an equilibrium operating temperature of the fuel cell stack in the electrolysis mode is selected independently from an equilibrium operating temperature of the fuel cell stack in the fuel cell mode to optimize at least one of an amount of fuel produced in the electrolysis mode and a unit cost of the fuel produced in the electrolysis mode.

39. The method of claim 20, wherein the reversible fuel cell system comprises a stack of solid oxide regenerative fuel cells.

40. The method of claim 20, wherein the reversible fuel cell system comprises a plurality of PEM fuel cells.

41. The method of claim 20, wherein the reversible fuel cell system comprises a fuel cell which generates electrical energy and an electrolyzer cell which generates fuel.

42. The method of claim 20, further comprising providing the fuel removed from the electrochemical system into an airborne vehicle, a water based vehicle or a land based vehicle.

43. The method of claim 20, further comprising providing the fuel removed from the electrochemical system into a chemical reaction in a chemical manufacturing process.

44. The method of claim 20, further comprising providing the fuel removed from the electrochemical system into an heating system of a building containing the reversible fuel cell system.

45. An electrochemical system, comprising:
a first means for cyclically operating in a fuel cell mode to generate electrical energy and reactant product from fuel and oxidizer and in an electrolysis mode to generate the fuel and oxidant from the reactant product and the electrical energy;

a second means for providing excess reactant product to the first means operating in the electrolysis mode from outside the electrochemical system, in addition to or instead of the reactant product generated by the first means in the fuel cell mode, such that fuel in excess of fuel required to operate the first means in the fuel cell mode is generated in the electrolysis mode over a predetermined number of operating cycles; and

a third means for removing the excess fuel generated by the first means operating in the electrolysis mode from the electrochemical system.

46. The system of claim 45, wherein the first means generates more fuel in the electrolysis mode than it consumes in the fuel cell mode over the predetermined number of cycles.

47. The system of claim 46, wherein the first means is a means for operating at a higher current level in the electrolysis mode than in the fuel cell mode over the predetermined number of cycles.

48. The system of claim 47, wherein:

the first means is electrically connected to a fourth means for generating electrical energy from sun light and for providing the generated electrical energy to first means during daytime to generate fuel; and

the first means is a means for generating electrical energy during night time, such that a night time load on the first means at least during a portion of the night period is lower than a peak load that the first means is capable of providing.

49. The system of claim 47, wherein the first means is a means for operating at a load lower than a peak load that the first means is capable of providing at least during a portion of a time that the first means operates in the fuel cell mode.

50. The system of claim 46, wherein the first means is a means for operating for a longer duration in the electrolysis mode than in the fuel cell mode over the predetermined number of cycles.

51. The system of claim 50, wherein:

the first means is electrically connected to a fourth means for generating electrical energy from sun light and providing the electrical energy to the first means during daytime periods to generate fuel;

the first means is a means for generating electrical energy during night time periods, wherein night time periods are shorter than daytime periods.

52. The system of claim 45, wherein the first means is electrically connected to a fifth means for generating renewable electrical energy and for using excess capacity to provide electrical energy to the first means operating in the electrolysis mode to generate the excess fuel.

53. The system of claim 52, wherein the fifth means is a means for generating electrical energy from sun light and for using the excess capacity during a first half of its designed lifespan.

54. The system of claim 52, wherein the fifth means is a means for generating electrical energy from wind and for using the excess capacity during periods when the wind speed exceeds a predetermined minimum wind speed required to generate a desired amount of electrical energy.

55. The system of claim 52, wherein the fifth means is a means for generating electrical energy from tidal force and for using the excess capacity during periods when the tidal force exceeds a predetermined minimum tidal force required to generate a desired amount of electrical energy.

56. The system of claim 45, wherein the second means for providing excess reactant product comprises a means for providing excess reactant product to the first means operating in the electrolysis mode from outside the electrochemical system in addition to a stored reactant product generated by the first means in the fuel cell mode.
57. The system of claim 45, wherein the second means for providing excess reactant product comprises a means for providing excess reactant product to the first means operating in the electrolysis mode from outside the electrochemical system instead of the reactant product generated by the first means in the fuel cell mode.
58. The system of claim 45, further comprising a sixth means for storing the fuel produced by the first means and a seventh means for storing the reactant product produced by the first means.
59. The system of claim 45, wherein:
the reactant product comprises water; and
the fuel comprises hydrogen.
60. The system of claim 45, wherein:
the reactant product comprises water and carbon dioxide; and
the fuel comprises methane.
61. The system of claim 45, wherein the third means is a means for providing the fuel removed from the first means into an airborne vehicle, a water based vehicle, a land based vehicle, a chemical reaction in a chemical manufacturing process, or a heating system of a building containing the first means.
62. The system of claim 45, further comprising an eighth means for selecting an equilibrium operating temperature of the first means in the electrolysis mode independently from an equilibrium operating temperature of the first means in the fuel

cell mode to optimize at least one of an amount of fuel produced in the electrolysis mode and a unit cost of the fuel produced in the electrolysis.

63. A method of operating a reversible fuel cell system, comprising cyclically operating the reversible fuel cell system in a fuel cell mode to generate electrical energy and reactant product from fuel and oxidizer at a first equilibrium temperature and in an electrolysis mode to generate the fuel and oxidant from the reactant product and the electrical energy at a second equilibrium temperature, wherein the first equilibrium temperature is different from the second equilibrium temperature.

64. The method of claim 63, further comprising selecting the first equilibrium operating temperature independently from the second equilibrium operating temperature to optimize at least one of an amount of fuel produced in the electrolysis mode and a unit cost of the fuel produced in the electrolysis mode.

65. The method of claim 64, wherein the first equilibrium operating temperature is selected to maximize the amount of fuel produced in the electrolysis mode.

66. The method of claim 64, wherein the first equilibrium operating temperature is selected to minimize the unit cost of the fuel produced in the electrolysis mode.

67. The method of claim 64, wherein the first operating temperature is selected by adjusting an amount of current density provided to the reversible fuel cell system.

68. The method of claim 64, wherein the first operating temperature is selected by adjusting an amount of the reactant product provided to the reversible fuel cell system.

69. The method of claim 64, further comprising:
providing excess reactant product to the reversible fuel cell system operating in the electrolysis mode from outside the reversible fuel cell system, in addition to or

instead of the reactant product generated by the reversible fuel cell system in the fuel cell mode, such that fuel in excess of fuel required to operate the reversible fuel cell system in the fuel cell mode is generated in the electrolysis mode over a predetermined number of operating cycles; and

removing the excess fuel generated by the reversible fuel cell system operating in the electrolysis mode from an electrochemical system in which the reversible fuel cell system is located.

70. The method of claim 69, wherein:

the reversible fuel cell system generates more fuel in the electrolysis mode than it consumes in the fuel cell mode over the predetermined number of cycles; and

the reversible fuel cell system comprises a stack of solid oxide regenerative fuel cells.